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Applying the ‘no-one worse off’ criterion to design Pareto efficient HIV responses in Sudan and Togo

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Introduction: Globally, there is increased focus on getting the greatest impact from available health funding. However, the pursuit of overall welfare maximization may mean some are left worse off than before. Pareto efficiency takes welfare shifts into account by ruling out funding reallocations that worsen outcomes for any person or group.

Methods: Using the Optima HIV model, studies of HIV response efficiency were conducted in Sudan in 2014 and Togo in 2015. In this article, we estimate the welfare maximizing and Pareto efficient allocations for these two national HIV budgets, using data from the original studies.

Results: We estimate that, if the 2013 HIV budget for Sudan was annually available to 2020 but with funds reallocated according to the welfare maximizing allocation, a 36% reduction in cumulative new infections could be achieved between 2014 and 2020. We also find that this is Pareto efficient. In Togo, however, we find that it is possible to reduce overall new infections but applying the Pareto efficiency criterion means that shifts in emphases cannot occur in the HIV response without additional resources.

Discussion: Protecting service coverage for key population groups is not necessarily equivalent to protecting health outcomes. In some cases, requiring Pareto efficiency may reduce the potential for population-wide welfare gains, but this is not always the case.

Conclusion: Pareto efficiency may be an appropriate addition to the quantitative toolset for evaluating HIV responses.

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Keywords: allocative efficiency, HIV modeling, HIV prevention, key populations, Pareto efficiency, Pareto optimality

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Introduction

The efficient allocation of health resources is an important objective for health systems as populations age, the global burden of noncommunicable disease grows, and health financing stagnates. Broadly speaking, efficiency measures whether the best outcomes are being obtained for a given budget [1], but to make use of this very broad definition it is necessary to understand what is meant by ‘best outcomes’, and what barriers might exist to obtaining them. Efficiency studies often focus on quantitatively answering the latter question [2], but the former is more subjective, and even if we agree on a way to quantify an individual’s health outcomes, a separate set of complications arises when it comes to aggregating across individuals to determine net social welfare [3,4].

Quantifying social welfare becomes pertinent when considering *allocative efficiency*, that is, evaluating how resources are allocated across interventions. A healthcare system can generally be considered allocatively efficient if no other allocation would increase overall population welfare. However, the pursuit of a welfare maximizing outcome may mean that some are left worse off than they were before. *Pareto efficiency* or *Pareto optimality* is an alternative efficiency criterion that considers these welfare shifts: an allocation is *Pareto efficient/optimal* if there is no other allocation that would make one individual better off without making at least one other individual worse off. (A third efficiency criterion, Kaldor–Hicks efficiency, combines aspects of both these criteria by allowing for hypothetical compensation of those made worse off. Thus, a welfare-maximizing outcome could be Kaldor–Hicks efficient even if not Pareto efficient. However, Kaldor–Hicks efficiency requires the assumption that utility is transferable, which is not the case for health.) Pareto efficiency is rarely used in health economics, because generally speaking, any reallocation of health resources will result in at least one person being worse off [5]. We therefore propose to consider a response Pareto efficient if no defined demographic or risk group can be made better off without some other group being made worse off. This population-group definition is less restrictive than an individual-level definition and potentially more useful, given that evaluation of health responses often considers the impact on certain population cohorts, particularly those at greater risk.

In this study, we compare two allocation strategies – welfare maximizing and Pareto efficiency – for evaluating HIV responses. We propose that it may be appropriate to aim for ‘group Pareto efficiency’ in the context of infectious diseases. We begin by presenting some theory for Pareto efficiency for infectious diseases. Next, we investigate HIV programmatic priority setting using two country examples, based on HIV allocative efficiency studies conducted in Sudan [6] and Togo [7]. To

investigate allocation strategies, we use Optima HIV, a mathematical model designed to facilitate estimation of the welfare maximizing allocation of HIV resources. We describe how the model’s optimization algorithm was extended to estimate Pareto efficient allocations. We show that, in Sudan, the welfare maximizing allocation was Pareto efficient, but in Togo the welfare-maximizing allocation was not Pareto efficient.

Methods

Theory of Pareto efficiency in infectious diseases

To outline the key theoretical aspects, we consider a simplified epidemic context with two programs, one targeted at female sex workers (FSW) and the other at people who inject drugs (PWID). A total budget of \$2m is split equally between the two programs. The number of new HIV infections acquired by FSW and PWID depends on how much of the budget is allocated to each program. Figure 1 presents two possible scenarios. In the first (Fig. 1a), there is limited mixing between FSW and PWID, so reducing new infections in one population does not greatly affect the other. In the second (Fig. 1b), injection is the primary mode of HIV transmission, and infections acquired by PWID are sexually transmitted to FSW. In this instance, it benefits both populations to shift more funding toward the PWID program.

Scenarios like those presented in Fig. 1b distinguish the theory of Pareto efficiency in infectious diseases from how it is usually applied in welfare economics, where it is assumed that people’s utility increases monotonically with the share of resources they are allocated. This implies that Pareto improvements are only possible via technical efficiency improvements, increasing budgets, or utility transfers. However, for communicable diseases, preventing a primary case in one population may avert multiple downstream infections due to the dynamic nature of pathogen transmission. Pareto efficiency has been considered in theoretical infectious disease models [8–10], but not extensively in real-world settings.

Using Optima HIV to determine welfare-maximizing and Pareto efficient allocations

Optima HIV is an epidemic model linked to a programmatic response module that can estimate the optimal allocation of a total HIV budget across different programs for a given objective and set of intervention cost functions [11]. The entire population can be divided into as many subpopulations as required to capture variation in vulnerability to HIV infection. We consider an example where the population P is divided into N subpopulations, denoted P_i ($i = 1, \dots, N$), and the HIV response has M programs with annual budgets B_j ($j = 1, \dots, M$). We call (B_1, \dots, B_M) allocation \mathbf{A} . The health outcomes of population P_i depend on \mathbf{A} , so we write $O_i(\mathbf{A})$ where O

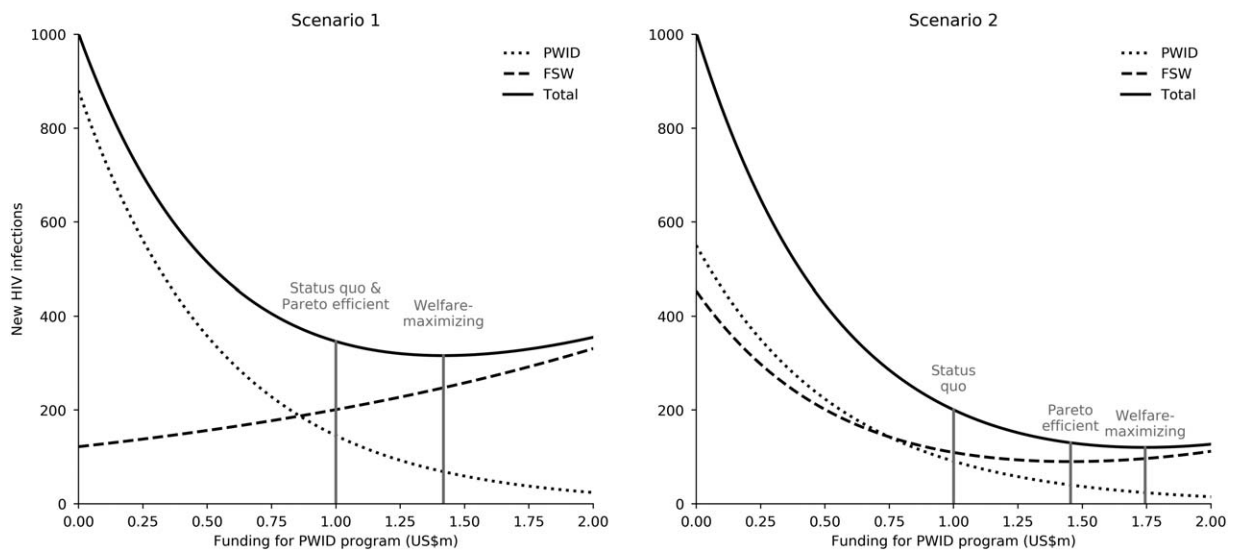


Fig. 1. Pareto efficiency and welfare maximization. The dashed, dotted, and solid black lines represent the number of new HIV infections acquired by female sex workers, people who inject drugs, and the total population, respectively. The status quo allocation is for US\$1m to be allocated to the people who inject drugs program and US\$1m to the female sex workers program. (a) A scenario with limited mixing between the two populations, so reducing new infections in one population doesn't greatly reduce infections in the other, although overall infections can be reduced by shifting funding to people who inject drugs programs. (b) A scenario where shifting funds to people who inject drugs also reduces infections in female sex workers, because the majority of infections in female sex workers are acquired through sexual contact with people who inject drugs.

stands for outcomes. The health outcome of the entire population is the sum of outcomes in each subpopulation, that is, $O(\mathbf{A}) = \sum_{i=1}^N O_i(\mathbf{A})$.

To determine the welfare-maximizing allocation, we choose the health outcome O of interest (typically new HIV infections, disability-adjusted life years, deaths, or another country-specific outcome), and find the allocation \mathbf{A}^* that solves the optimization problem $\min_{\mathbf{A}} O(\mathbf{A})$, subject to the constraint that the overall budget $B = \sum_{j=1}^M B_j$ remains constant.

Extending this to include Pareto efficiency requires the additional constraint:

$$\min_{\mathbf{A}} O(\mathbf{A}) \text{ subject to } O_i(\mathbf{A}) \leq O_i(\mathbf{A}_B),$$

where \mathbf{A}_B is the baseline allocation. It is easy to show that the \mathbf{A}^* that solves this is Pareto efficient, as the constraint combined with the minimization ensures that it is welfare-maximizing with no subpopulation worse off.

Overview of HIV allocative efficiency studies conducted in Sudan and Togo

In 2014, Sudan's national AIDS program reviewed its National Strategic Plan on HIV and prepared a concept note for the Global Fund for AIDS, Tuberculosis and Malaria (the Global Fund), and in 2015, the Government of Togo underwent the same process. Each country approached the World Bank with a request to conduct

allocative efficiency analyses to inform the prioritization of their HIV responses and the development of their Global Fund concept notes. In both cases, analyses focused on how HIV resources should be allocated for greatest epidemiological impact. The Optima HIV model was applied in both country's processes.

Evaluating funding allocations in Sudan and Togo

In Sudan, the primary objective of the study was to minimize new infections over 2014–2020, which meant determining the welfare-maximizing allocation of the HIV budget. In Togo, the primary objective was to minimize a combination of deaths and new infections over 2015–2020 whilst ensuring that infections did not increase in any subpopulation. This meant exploring whether there were allocations that were Pareto superior to the 2014 allocation. For this study, we estimated both the welfare-maximizing and Pareto efficient allocation for both countries.

Results

In Sudan, we found that, even if overall investment in HIV does not increase, there is a welfare maximizing allocation that could attain a 36% reduction in cumulative new infections over 2014–2020 (Fig. 2a). This reallocation is also estimated to reduce infections in each subpopulation and is therefore Pareto efficient.

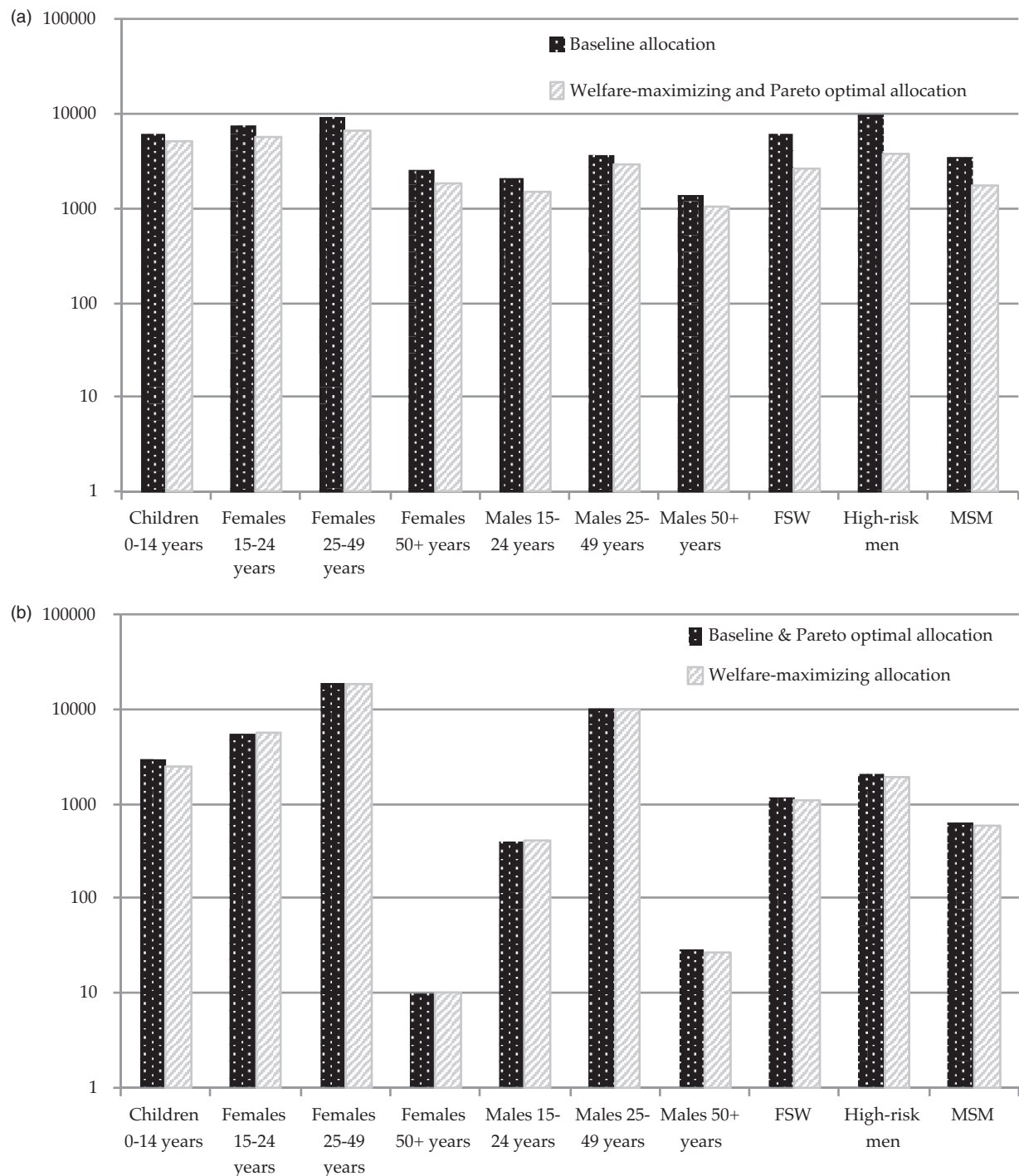


Fig. 2. Cumulative HIV infections projected under the baseline, Pareto efficient, and welfare-maximizing allocations of HIV budgets in (a) Sudan and (b) Togo. The allocations are shown in Table 1 of the Supplementary materials, <http://links.lww.com/QAD/B438>.

In contrast, in Togo, we found that the latest reported allocation of investments was already close to welfare maximizing (Fig. 2b). However, the welfare-maximizing allocation implied a 7% increase in cumulative new infections among males aged 15–24 years (despite a 5% reduction in new infections overall), and thus is not Pareto efficient. We found no Pareto-improving

allocations of the HIV budget in Togo, indicating that any shift from status quo investment patterns would make at least one subpopulation worse off.

Complex epidemic dynamics mean that shifting funds away from a particular population may not translate to an increase in infections in that population. This can be

observed for Sudan, where new infections among the general population were projected to decrease despite defunding prevention programs targeted at this population (effectively a kind of compensation: those who gain from reallocation ‘compensate’ others by lowering their HIV acquisition risk). Likewise, mother-to-child transmission (MTCT) was projected to decline even if funding for prevention of MTCT were to decrease. In both cases, this is due to the large proportion of new infections ($\sim 1/3$ in 2014) contributed by sex work [6], and the relative cost-effectiveness of preventing infections among sex workers.

Discussion

In the context of infectious diseases, preventing primary cases may avert multiple downstream infections, so programs that are most effective at averting primary cases are not necessarily those that will maximize overall population health. Mathematical models have proven useful for estimating the cumulative downstream effects of responses [12]. In this study, we proposed an extension for how models can be used, namely as a tool for estimating the scope for Pareto improvements.

One limitation of this study is that the type of Pareto efficiency we have considered is not the typical individual-level definition, and is thus sensitive to the subpopulations considered. For example, the welfare-maximizing allocation in Togo was characterized as Pareto inferior to the baseline allocation because it meant an increase in infections among males aged 15–24 years. However, had a different population grouping been defined for analysis (e.g., grouping all males aged 15–49 years), the welfare-maximizing allocation would have been Pareto efficient. If the subpopulations are small enough, it may be impossible to find a Pareto superior allocation. We also do not consider potential redistributions of health within subpopulations. However, within HIV there are standard key populations (e.g., FSW, MSM, and PWID) of interest, and protecting the health outcomes of these groups could be done fairly consistently. The existence of a Pareto superior allocation also depends on the programs considered: if programs are divided into intervention implementation modalities, finding a Pareto optimal allocation may be easier. We also note the limitations of Pareto efficiency itself as a social choice rule. Its drawbacks (including the disregard of equality, social welfare, or resource wastage) are well known, and assuming that status quo health outcomes are worth protecting may not always be reasonable. Other factors, such as equity and fairness, need to be considered to overcome these limitations.

Allocative efficiency studies have been conducted in numerous settings over the past decade by our group and others [13–17]. Although decision-makers have

recognized the importance of optimally allocating funding to get the best possible health outcomes, it is still common to incorporate ethical, logistical, and political constraints to protect the interests of various groups and ensure that modeling recommendations are practicable. However, protecting intermediary health measures (such as program coverage) may not be the most effective way to protect the health outcomes. Thus, Pareto efficiency may be a useful addition to the standard set of tools for evaluating responses to infectious diseases, even though it cannot be the sole criterion by which distributional fairness can be assessed.

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Author contributions: R.M.S.: conceived the study, wrote the Pareto efficiency algorithm, conducted the Sudan analyses and wrote the first draft; H.H.-B.: conducted the Togo analyses, contributed to the discussion on social optimality; J.P.-G.: conducted the Togo analyses; L.G.: conducted the Togo analyses; J.S.: supervised the Togo analyses; C.C.K.: reviewed the Pareto efficiency algorithm; D.J.K.: provided technical assistance to Togo and code development; R.M.-H.: updated the Sudan and Togo analyses; S.L.K.: updated the Sudan and Togo analyses; D.P.W.: provided conceptual guidance/supervision. All authors contributed to the editing of the article.

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Conflicts of interest

There are no conflicts of interest.

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